sophisticated than any ever mass-marketed in this country. Those who have seen HDTV receivers in operation say that, once the units are properly set up, they are easier to use than today's TVs. Nevertheless, you can make a strong case that the new receivers embody technology that is even more complex than that of high-end PCs.

It has been approximately eight years since the US electronics industry began work on the kind of HDTV system that the new TV sets embody. The ATSC (Advanced Television Systems Committee, www.atsc.org) is the group behind the standards that form the basis for over-the-air HDTV in the United States. Currently, in North America and several other parts of the world, analog standard-definition TV (SDTV) conforms to National TV Systems Committee (NTSC) standards. If the Federal Communications Commission (FCC) gets its way, current NTSC transmission standards will give way to ATSC standards in the United States well before the end of the next decade.

In other words, most Americans will have to scrap their TVs and VCRs or buy converters to allow those units to display and record programs transmitted in ATSC's digital formats. Compatibility issues extend even to handheld videocameras, which produce analog outputs that are incompatible with digital receivers. Nevertheless, the plan is to convert consumer video products to a digital interface.

How closely reality follows that plan is another matter, however. Although consumers have shown surprising willingness to replace obsolete PCs, the need to discard working electronic entertainment equipment has rarely been an issue. Public reaction to such forced obsolescence remains to be gauged.

A US STANDARD

The ATSC expects its US standards to govern land-based over-the-air TV broadcasting not just in the United States, but throughout North America and in a few Asian countries. Europe, Japan, and Australia are planning different HDTV standards, however. Unlike the ATSC system, which uses eight-level vestigial-sideband (8VSB) modulation for over-the-air transmission, the European, Japanese, and Australian systems use orthogonal frequency-division multiplexing (OFDM).

The ATSC version of 8VSB uses the same 6-MHz channel width as NTSC. The system combines groups of 3 bits into symbols, which it transmits sequentially. Each symbol is represented by one of eight amplitude levels. A root-raised-cosine filter limits the signal bandwidth. Only the amplitude of the signal's in-phase component is important. The symbol rate is 10.76 MHz; the "payload rate," the maximum rate at which the system can transmit meaningful data, is 19.39 Mbps. Whereas 19.39 Mbps is appreciable, it may not seem especially high for a 6-MHz-wide channel. Remember, though, that because the system is designed for over-the-air broadcasting, it uses a significant part of its bandwidth for forward error correction (FEC).

Proponents of 8VSB maintain that researchers know much more about the behavior of 8VSB-modulated signals than they know about the behavior of signals modulated with the newer OFDM. OFDM, which is more computationally intensive than 8VSB, uses thousands of quadrature-

modulated carriers to transmit large quantities of data at a low symbol rate. Consumer-product OFDM implementations capable of handling video-bandwidth signals in real time only recently became practical, as a result of the dramatic performance increases and price decreases in digital processors.

A major factor in the ATSC's choice of 8VSB was the need to keep over-the-air HDTV signals and NTSC transmissions from interfering with each other. During the transition from analog to digital transmission, the two systems must share the North American TV spectrum. NTSC's video carrier uses analog VSB modulation; 8VSB minimizes interference to and from NTSC signals. Although they insist that 8VSB is more robust than OFDM, 8VSB partisans agree that the industry needs more data on how both signal types behave in the presence of impairments.

THEY TRIED TO GO IT ALONE

The history of HDTV dates back much further than to the formation of the ATSC. Many companies worked to develop their own HDTV systems but eventually joined forces within the ATSC, which combined their best ideas into one system. The ATSC standard could not exist without some truly outstanding engineering. This engineering solved problems that, as recently as a decade ago, industry experts believed were insoluble in mass-marketed products. The experts thought that the products would have to be so expensive that nobody would buy them.

The most obvious examples of the ATSC's elegant technology are the video-decompression algorithms. Because of them, a 6-MHz-wide channel can carry video that contains twice the NTSC's number of scan lines per frame and more than twice the NTSC's number of pixels per line. Thanks to advances in IC technology, these algorithms run in real time in products that, despite current high prices, ultimately won't be much more expensive than NTSC TVs.

Nevertheless, HDTV's most nettlesome challenges weren't technological. The path through the HDTV thicket required resolving business-related issues whose complexity became as mind-boggling as that of the technological problems. Several times, technology enabled the standard to overcome issues that, at the core, weren't technical at all. Probably the best example of technology's allowing the resolution of such an issue was in the interlaced-versus-progressive-scan controversy.

AT A GLANCE

▷ For at least the next year, the high cost of high-definition-TV (HDTV) receivers (approximately $5000), as well as the spotty availability of signals and programming, will deter early adopters.

▷ Incompatibility with existing receivers, VCRs, handheld cameras, and cable-TV hookups is another deterrent.

▷ Even in strong signal areas, manufacturers must resolve uncertainties about whether indoor antennas work satisfactorily.

▷ During the transition to HDTV, broadcasters face high costs for producing programs in wide- and narrow-screen formats.

▷ Some broadcasters are asking whether they could better use the newfound bandwidth to transmit multiple standard-definition programs instead of transmitting HDTV signals.

INTERLACED SCANNING

The NTSC standard uses interlaced scanning, as do nearly all other analog-TV standards worldwide. Interlaced scanning is the norm in TV and in cases in which motion pictures use electronic images. In interlaced scanning, the CRT beam traces twice through the screen to produce a single frame; that is, a frame consists of two fields. (Although most interlaced flat-panel displays use no electron beams, these displays illuminate their pixels in the same order as do CRTs that produce interlaced displays.)

In NTSC format, the pixels light up from left to right and top to bottom approximately 60 times/sec, but the frame rate is half that amount—29.97 frames/sec. Each field illuminates half of the pixels. Odd-numbered fields illuminate the pixels in odd-numbered lines. Even-numbered fields illuminate the pixels in even-numbered lines—those lines that lie between the lines of pixels that the odd-numbered fields illuminate.

The computer industry, on the other hand, has adopted progressive scanning because users often perceive annoying flicker in interlaced computer displays. In progressive scanning, there is only one field per frame. In each frame, each pixel lights up once in a top-to-bottom, left-to-right order. To further reduce flicker, many computer-display formats use frame rates much higher than 30 frames/sec. In PC displays, a popular though not universal rate is 72 frames/sec.

Computer and software manufacturers wanted to ensure that the ATSC standards could easily accommodate the many potential applications that marry computer and TV technology. Therefore, for a time, the progressive-scan-versus-interlaced-scan controversy and the frame-rate issue threatened to derail ATSC. Ultimately, though, the standards committee devised ways to accommodate a variety of formats (**Table 1**). The **table** includes formats that specify several frame rates, two aspect ratios, and both interlaced and progressive scanning.

TOUGHEST CHALLENGES

Now that deployment has begun, the ATSC system faces its toughest tests. How will the system behave in the real world, and how quickly will broadcasters and the public espouse it? The history of moving entire nations to incompatible, albeit improved, TV standards suggests that the FCC's timetable for phasing out NTSC by 2006 could be optimistic. Moreover, in none of the previous large-scale upgrades did other types of systems vie with land-based over-the-air transmitters for delivering TV programming.

Several systems compete with land-based over-the-air HDTV, however. Approximately 80% of US homes are in areas that cable systems serve, and almost 80% of those homes (or approximately 65% of all US homes) subscribe to cable service. In addition, direct-broadcasting-satellite (DBS) systems bring TV programming to the homes of a rapidly growing number of viewers.

The existence of these alternative program-delivery systems—not to mention video stores—has made more than one industry observer question the continued need to devote large amounts of the RF spectrum to land-based over-the-air TV broadcasting. Nevertheless, US broadcasters are a vocal and well-financed group with abundant political connections. So, at the moment, there is zero chance of their having to buy spectrum space from the

government at FCC auctions, as operators of many communications services must now do. And you can simply forget about the idea of terrestrial radio and TV broadcasting's having to entirely relinquish the portions of the spectrum they now occupy.

Although the ATSC standard is compatible with cable, adopting ATSC would require cable-system operators to make a substantial investment in upgrading their facilities. Moreover, system operators that have committed to digital transmission seem determined to use a quadrature-amplitude-modulation (QAM) system. That system is incompatible with the 16-level VSB (16VSB) modulation that ATSC defines for signal transmission via cable. The 16VSB version of ATSC transmits data at 39.78 Mbps, twice the rate of the over-the-air implementation. According to ATSC advocates, 16VSB is compatible with 8VSB, and it also delivers performance identical to that of the cable QAM system.

CABLE GOES ITS OWN WAY

The US cable-TV industry's apparent choice of a modulation technique that is incompatible with 8VSB has unpleasant implications for prospective purchasers of HDTV receivers. Initially, the incompatibility may force these viewers to choose between cable and over-the-air transmissions as the source of their HDTV programming. To overcome the incompatibility, viewers may require separate converters to allow viewing of cable-delivered HDTV signals on ATSC-compatible receivers. Eventually, receivers that accommodate both systems may become available, but a cost penalty for the compatibility features seems likely.

Whereas DBS systems *could* deliver ATSC signals to viewers' homes, existing DBS systems do not do so; they use proprietary digital technology. DBS systems currently deliver only NTSC-compatible SDTV signals. Converting DBS systems to ATSC would involve a substantial investment—in this case, upgrading a physical plant that, unlike those of most cable systems, is nowhere near fully amortized.

Terrestrial TV broadcasters face thorny problems with upgrading their own facilities. On the studio and production side, screen shape is a major issue. Although the ATSC standard supports 14 SDTV and HDTV display formats, some of which use NTSC's 4×3 aspect ratio, the HDTV formats use a wider 16×9 aspect ratio. During the transition from SDTV to HDTV, broadcasters will have to produce programming in both aspect ratios.

Although automating the simultaneous creation of programs in both aspect ratios appears technically feasible, the equipment will probably be complex and expensive. If a program exists in a 16×9 aspect ratio, the conversion equipment will have to locate the areas in which there is motion, place the center of the frame on the moving object, and crop the areas at the periphery.

LOCATING THE OTHER TRANSMITTER

Then there is the issue of transmitter locations. The FCC's plan for implementing terrestrial HDTV broadcasts involves assigning all TV stations a second channel for use during the transition. Most of these stations cannot simply mount a second antenna on an existing tower, however; most towers can't support the additional weight. Insiders say antenna manufacturers are addressing this problem by developing replacement antennas that can transmit at two widely different frequencies. (Most VHF stations—those that operate on channels 2 through 13—have HDTV assignments on UHF channels 14 through 69.)

Reportedly, though, new antennas can't solve some stations' siting problems. The FCC intended to develop an allocation table that would permit each station to transmit both NTSC and ATSC signals from the same site without interfering with or receiving interference from other stations. In a few cases, however, such allocations have proved unworkable. (For example, the station could not deliver a sufficiently strong signal to the city of license.) Such stations cannot colocate their HDTV transmitters with their SDTV facilities.

Meanwhile, environmentally aware communities have become increasingly hostile to the location of tall antenna towers within their borders. Therefore, stations, particularly those in densely populated regions, are experiencing great difficulty in obtaining approval for the necessary new antenna sites. The FCC is attempting to provide relief, but the legality of federal regulations that override local zoning is subject to court challenges.

Even if most stations ultimately succeed in constructing facilities at or near the sites they desire, ATSC implementation isn't out of the woods. Construction delays will raise costs and are likely to add substantially to the FCC's timetable for phasing out NTSC transmissions.

TABLE 1—ATSC IMAGE FORMATS

Horizontal lines (vertical resolution—lines)	Pixels per line (horizontal resolution—lines)	Aspect ratio	Frame rate (frames/sec[1])
1080	1920	16×9	30I, 30P, 24P[2]
720	1280	16×9	60P, 30P, 24P
480	704	16×9 and 4×3	60P, 30I, 30P, 24P
480	640	4×3	60P, 30I, 30P, 24P
Basic NTSC broadcast format			
525 (484 active)	330	4×3	30I

[1]Additional variations exist: 24 is shorthand for 23.976 and 24 frames/sec, 30 is shorthand for 29.97 and 30 frames/sec, and 60 is shorthand for 59.94 and 60 frames/sec.

[2]P denotes progressive scanning; I denotes interlaced scanning.

MORE—NOT BETTER—SIGNALS

With those disturbing issues as a backdrop, some broadcasters have started to openly question whether they should convert to the 16×9-aspect-ratio HDTV formats. ATSC triples or quadruples the amount of information a 6-MHz channel can carry. HDTV receivers will be compatible with a variety of formats; broadcasters can choose the format they consider most appropriate for each program. Some broadcasters ask whether simultaneously transmitting three or four SDTV programs would represent a better use of a channel than transmitting one HDTV program. Although viewers would need converters to receive and demodulate the signals, the converters could deliver NTSC signals to existing TV sets.

The cost of the converters would be only

about a third of an HDTV receiver's $5000 (or higher) cost. Moreover, a station's revenue from transmitting three or four programs at once would be several times what the station could derive from transmitting a single program. And the greater program variety would make it easier for terrestrial over-the-air stations to compete with cable and DBS systems. Indeed, at least some of the additional signals might become subscription channels. These channels would bring stations a monthly stream of viewer fees that have been unavailable to most US land-based over-the-air stations.

INSATIABLE DEMAND

Nevertheless, the history of broadcast-service innovations indicates that, once the public awakens to the benefits of an improved service, the demand becomes insatiable. Historically, though, the awakening of demand has taken years, not months. For example, FM was widely available for more than 20 years before it became the dominant form of audio broadcasting in the United States.

Even when the new service is backward-compatible with the old, the public espouses the new service much more slowly than electronics manufacturers would like. It took almost 10 years for NTSC-compatible color TV to fully displace black-and-white TV.

On the other hand, DBS systems' ability to gather millions of subscribers in a few years has given broadcasters and hardware manufacturers hope that the old timetables no longer apply. Still, DBS did not require outlays of $5000 or more for new TV sets, or even $1500 for equipment to convert the new signals to a form compatible with existing sets.

In addition, when DBS became available, system operators had already proved their ability to reliably deliver high-quality signals to users' homes. Although manufacturers have extensively tested 8VSB and proponents have high confidence in it, many questions remain about reception of over-the-air ATSC broadcasts. Even ATSC advocates believe that indoor antennas, such as rabbit ears, loops, and bow ties, will prove unsatisfactory in many locations. Those locations include strong-signal areas where such antennas readily pick up NTSC signals. The National Institute of Standards and Technology (NIST) has proposed a project that could lead to a resolution of such problems. You can see this proposal at www.atp.nist.gov/www/comps/briefs/98040024.htm.

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IT'S AN ANALOG WORLD AFTER ALL

The irony of ATSC reception is that, even though 8VSB impresses digital information onto the RF carrier, the signal that carries the information to your house is analog. Most of the impairments that affect the reception of analog transmissions also affect the reception of over-the-air 8VSB transmissions.

There is an important difference, however. As analog signals become weaker, reception degrades gradually—TV pictures become snowier. Conversely, as digitally modulated signals degrade, you are unlikely to notice any changes until you suddenly receive no usable signal at all. The screen goes to solid black or blue, and the sound ceases. Once the receiver "loses" the signal in this way, there is often an uncomfortably long wait until the program reappears. The receiver needs this interval to reacquire the signal.

There are reports that early versions of ATSC receivers become confused and begin to search for other signals in such situations. The manufacturers insist that such problems are software bugs that they will soon resolve.

Still, engineers, station operators, and the public need to evaluate the severity of the problems. Engineers have voiced concerns about seasonal effects. Someone who sets up an HDTV receiver in the winter when the trees are bare may no longer receive a signal in the spring when new leaves appear.

THE PLANE! THE PLANE!

And engineers don't feel that they fully understand the effects on ATSC signals of airplanes flying overhead. With analog TV, airplanes cause signals to "flutter" at varying rates. The flutter results from wide swings in signal strength that occur when reflections from the airplane alternately cancel and reinforce signals arriving directly from the transmitter. Although ATSC receivers supposedly tolerate much larger signal-strength variations than do NTSC receivers, the rapid fluctuations may necessitate special measures to keep ATSC receivers from "losing" incoming signals.

Currently, engineers believe that, everything else being equal, delivering acceptable signals over equivalent coverage areas requires considerably less effective-radiated power (ERP) with ATSC than with NTSC. But at the frequencies that TV uses in North America, antenna height is important. With either ATSC or NTSC, a station whose antenna height above average terrain (HAAT) is 300m requires approximately four times the ERP to equal the coverage of a station whose antenna height is 600m. However, tall towers' high cost and low popularity will force many HDTV transmissions to emanate from antennas atop shorter towers than those used for NTSC. Therefore, the ERPs of ATSC and NTSC signals will often be similar.

AWESOME PICTURES

People who have viewed ATSC HDTV programs on large-screen receivers that display the images' full resolution generally come away in awe. The high-fidelity, multichannel 3-D sound only enhances the effect. Of course, people who regularly see and hear these high-quality transmissions will become jaded soon enough and will think that such quality is nothing out of the ordinary.

Nevertheless, first-time viewers of HDTV images report that they have had to become accustomed to some surprising effects. These effects are the result of the image compression that squeezes such high-resolution images into the 6-MHz channel. No artifacts are noticeable in motionless backgrounds, which appear in stunningly clear detail. When an object moves, however, it momentarily blurs and develops blocklike features.

Some people find it disconcerting to watch objects that exhibit fine detail when stationary but morph into barely recognizable forms when they move. Supposedly, the human eye cannot perceive detail in rapidly moving objects. Apparently, though, the brain wants control over which details it ignores. It doesn't want to cede that control to a TV set—even a very smart, high-tech TV set. □

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